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Band parameters of MQWs heterostructures InGaAs/GaAs: magnetooptical study

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Abstract. Investigation of the optical absorption and magnetoabsorption spectra of a set of $In_xGa_{1-x}As$/GaAs strained MQWs with different well widths and different Indium content x has been carried out at 1.7 K in the presence of the magnetic field up to 7.5 T. The measurements performed on the free standing samples have allowed to obtain well-resolved oscillatory spectra and to reconstruct Landau level positions. An effective masse of the electron and other parameters of the InGaAs/GaAs MQW heterostructures depending on the Indium concentration were estimated.

Introduction

The ternary alloys $In_xGa_{1-x}As$ grown on GaAs attract much attention due to their applications in micro- and optoelectronics. Precise knowledge of the band parameters of these alloys is required for these applications. Determination of band parameters is a non-trivial problem because of their dependence on the compound x. In a major part of publications on this subject, for the sake of simplicity, the linear interpolations or extrapolations are used. Sometimes this approach is too rough to yield satisfactory results. Especially, it concerns the calculation of a heavy-hole mass. Here we report a detailed investigation of the magnetoabsorption spectra usually assumed as the best source of band parameter data. Indium compound effect on the conduction and valence band effective masses in $In_xGa_{1-x}As$ alloys is under study.

Our technique is based on the low-temperature light absorption measurements in the presence of an external magnetic field. Landau oscillations in these spectra represent a signature of so-called "diamagnetic excitons" [1], which are formed at strong magnetic fields. To restore true Landau fans from the measured spectra one has to add to the experimental transition energies the calculated exciton binding energies R_B as is discussed in detail in [2]. Knowing the slope of true Landau fans, following [1, 2] one can deduce the cyclotron masses of electrons and holes.

Thus for a correct determination of the band parameters one should be able to determine R_B with a good precision. In general a binding energy is a complex function of magnetic field and all quantum numbers of the problem, $R_B(N, l, M, L_z)$, where N is a quantum number of the electron (hole) state in the well, l is a Landau quantum number, M is a momentum projection into the magnetic field direction, L_z is a width of quantum well. The inevitable mixing of light- and heavy-hole states complicates the calculation.

1 Samples and experimental procedure

The $In_xGa_{1-x}As$ samples were grown by molecular beam epitaxy on (100) oriented GaAs substrates. Characteristics of the studied samples are listed in Table 1. $Al_{0.5}Ga_{0.5}As$ 0.5 μm thick stop layers were grown in order to allow complete removing the substrates by chemical etching. This has allowed to measure all details of transmission spectra which were then used to restore the spectral dependence of the absorption coefficient in the structures.

Magneto-optical measurements have been carried out at $T = 1.7$ K in a pumped liquid Helium cryostat with a superconducting solenoid, which allowed to create magnetic fields up to 7.5 T. The free samples were immersed in the liquid helium. The spectra were obtained for left- and right-circularly polarized light in the Faraday geometry using a high-transmission diffraction monochromator.

Table 1. MQWs Indium contents x, and layer thicknesses L_z, L_B deduced from the X-ray diffraction measurements. N is the number of periods of multiple quantum well structures, FWHM is the width of the spectral lines directly deduced from the absorption spectra.

Samples	x	L_z (nm)	L_B (nm)	N	FWHM (meV)
1	0.033	9.3	89.7	30	0.8
2	0.044	8.5	83.7	20	0.9
3	0.045	9.0	82.2	20	1.1
4	0.062	8.8	75.8	20	1.7
5	0.066	6.3	79.4	20	1.6
6	0.132	4.4	14.7	30	6.6
7	0.161	7.5	33.1	30	5.0
8	0.209	5.0	13.0	30	10.3
9	0.225	4.6	23.7	30	11.9

As one can see from the Table 1, low Indium concentrations ($x = 0.033-0.066$) correspond to the best quality of samples[1] and ultra-narrow spectral lines. To exclude strain relaxation effects the barriers in multiple QW structures have been made much thicker than wells. Compound x, well width L_z and barrier width em L_B were determined with use of X-ray diffraction spectroscopy[2].

2 Results and discussion

Optical transmission spectra measured after removing a substrate without magnetic field and under $B = 1-3$ T of one for our samples are shown in Fig. 1. In [3] we have studied optical transmission spectra either before or after substrate removal. Free standing samples exhibit much more spectral details. Two kinds of spectral lines in zero field having different scales of absorption modulation can be distinguished. The low amplitude lines correspond to the transitions on the (In,Ga)As well electron level,while stronger spectral features correspond to the transitions in the GaAs barrier (4) described in the terms of the exciton-polariton branch quantization combined with weak strain effects [4]. The lines (1 and 2) are associated with HH1E1 exciton ground (1s) state and first excited (2s) state, and the series of lines correspond to the light hole exciton states LH-E1 (3). It is worth to note that for such a small In contents there are no other allowed optical transitions in the system according to the calculated energy scheme.

Magnetic fields higher than 1 T cause oscillations in the absorption spectrum (Fig. 1). A considerable number of absorption maxima are recorded, sometimes more than 20 peaks. The fact of such a large number of strong oscillations observed in the magnetoabsorption, attests rather high quality of the quantum-well layers. This oscillatory behavior of the

[1] Samples were prepared in Optical Science Center, University of Arizona, and kindly placed at our disposal by H. Gibbs and G. Khitrova.

[2] The X-ray measurements were performed with N. N. Faleev in A. F. Ioffe Physico-Technical Institute.

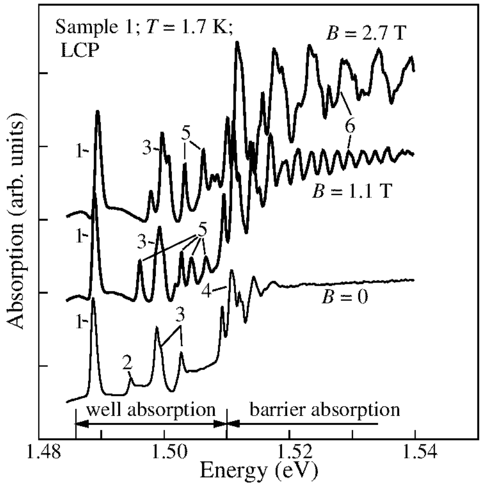

Fig. 1. Absorption spectra for MQWs $In_{0.033}Ga_{0.067}As/GaAs$ without magnetic field and under $B = 1.1$ T; $B = 2.7$ T: 1, 2—heavy hole exciton states; 3—light hole excitons; 5, 6—magnetoexciton maxima for QWs and GaAs barrier, respectively.

magnetoabsorption maxima is characteristic of the interband magnetoabsorption of quantum wells and has been observed previously in the AlGaAs/GaAs system [5]. It appears when the strong-field criterion $\beta = \hbar\Omega/2R_0 \gg 1$ (where R_0 is the binding energy of an exciton for $B = 0$ and (Ω is the sum of cyclotron frequencies of electrons and holes) is not satisfied by the excitonic ground state, and is observed only when excited states of the exciton participate in the absorption.

Heavy hole exciton transitions dominate in the magnetoabsorption spectra. To restore true Landau fans one has to add the calculated binding energies to all experimental peak energies. This, as well as the next procedure, can be assumed as a good confirmation for calculated magnetoexciton binding energies. The reconstruction of Landau fans in the units $y = \hbar\omega_0(l + 1/2)$, where $\omega_0 = eB/mc$ is the free electron cyclotron energy proportional to the magnetic field B, for all samples listed in Table 1, is shown in Fig. 2. Such scale collects all the experimental points belonging to the different Landau states into one curve, as one really can see in Fig. 2. This allows us to estimate the reduced effective mass μ of an electron and hole in the plan of the quantum well, from the slope of the reconstructed straight line for the transitions between Landau subbands $\Delta E/\Delta B$.

Unfortunately, we have not possibility to separate contributions of electron and heavy hole in the obtained reduced masses. Moreover, obtained data belong to the samples with different quantum well width L_z. After taking correction on electron nonparabolicity depending on L_z, we can choice heavy hole masses that allows us to obtain the dependence of m_c^* on the Indium concentration (see Fig. 3), which not contradict to the known dependence of m_c^* on x bulk material (for example, $m_0^{-1}m_c^* = 0.0660 - 0.0537x + 0.0116x^2$; see [6]). By such a way, we define the compositional dependence of the valence band effective masses for heavy hole: $m_0^{-1}m_{\mathrm{HH}}^*(x) = 0.385 - 0.88x + 0.86x^2$. Comparing this value with known literature dependence for heavy hole mass, we can talk about absence of the substantional mixing of light- and heavy-hole states in given heterostructures with heavy holes strongly separated from light holes by strain. Heavy hole masses in MQW were studied theoretically in [7] taking into account both light hole tunneling and changes due to deformation of a layer. Following [7] m_{HH}^* in the first quantization level (HH1)

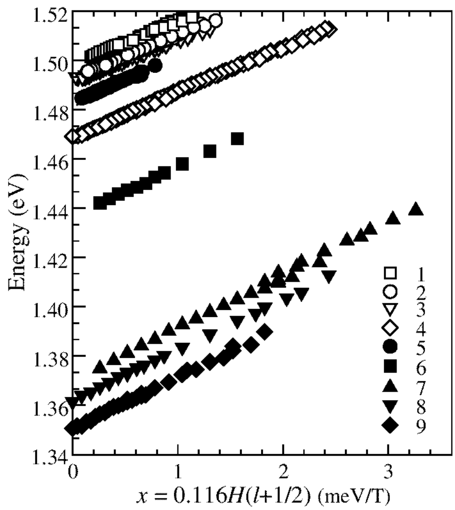

Fig. 2. Positions of maxima in the magnetoabsorption corrected for the binding energy of diamagnetic excitons plotted as a function of the cyclotron energy of a free exciton and the Landau number $(l + 1/2)$ for $In_xGa_{1-x}As$/GaAs MQW samples listed in Table 1.

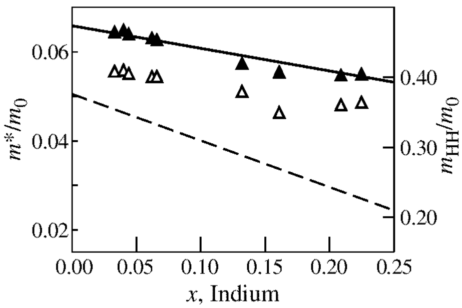

Fig. 3. Dependences of the electron and hole effective masses in $In_xGa_{1-x}As$ alloys on the Indium concentration. Triangles are reduced masses obtained directly as $\Delta E/\Delta B$ in Fig. 2, black triangles are after nonparabolicity corrections, and dotted line is supposed m^*_{HH}. Solid line is the dependence of electron effective mass from [6].

should be much higher then in unstrained QWs, approaching to the bulk mass, what largely explains the obtained result.

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